The effect of social proximity on fear conditioning: A virtual reality study

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Abstract

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Invasions of personal space automatically trigger fearful responses and yet little is known about the relationship between personal space and fear conditioning. We hypothesized that fear extinction would be weakened and fear renewal would be strengthened for a human avatar invading participants' personal space as compared to a human avatar safely outside of participants' personal space. We tested this hypothesis using a within-subject (n = 15) design wherein four human avatars, two close and two far, appeared in front of participants while they traveled down a virtual reality environment that appeared like a long hallway. During the acquisition phase, one human avatar from each distance was paired with mild electrical stimulation. The context of the virtual reality environment changed during the extinction phase and then returned to its original state in order to test contextual renewal after extinction. We found no significant differences in skin conductance responses between human avatars in the extinction phase, but we did find a main effect of distance (($F(1,14) = 13.043$, $p = 0.003$) and a significant interaction effect between distance and CS type ($F(1,14) = 8.66$, $p = 0.012$) during renewal. Thus context and personal space interact during return of fear phenomena. These findings have implications for our understanding and treatment of PTSD.

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Introduction

Personal space is the area that individuals maintain around themselves with the purpose of protecting themselves from harm (Kennedy, D.P., Glascher, J., Tyszka, J.M., Adolphs, R, 2009). The actual distance required differs culturally; Latin, Asian, and Arab people prefer closer interpersonal distances than Northern European and North American people (Hogh-Olesen, H., 2008). However, the concept of a "personal bubble" exists in every culture across human history, and invasion into that bubble automatically triggers acute discomfort and defensive behaviors. The experience of personal space invasions has taken on particular significance in the past couple decades, as increased urbanization has forced humans to live in denser social environments than ever before. As humans interact with each other at closer and closer interpersonal distances, the risk of social conflicts and interpersonal threats increases, suggesting that our emotions are partially regulated by social proximity (Dye, C., 2008). One emotion that seems particular affected by proximity is the feeling of fear. The goal of the current study is to determine whether invasions of personal space can affect fear extinction and fear renewal in a virtual reality environment.

The human experience of fear

Regardless of how subjectively unpleasant we may find them, emotions possess an evolutionary advantage. Fear can be thought of as the emotional middleman between threatening stimuli and defensive responses (Adolphs, R., 2013), and human defensive responses are innately organized patterns of behavior that have successfully protected us

from harm in our evolutionary history (Fanselow, M. S., & Sterlace, S.R., 2014). We need fear to activate our behavioral defensive responses, and we need those responses to protect ourselves from danger.

However, the world that humans live in is complex and often confusing, and thus threats are only probabilistically related to harm. Not every threat will lead to harm, and thus our fear responses will not always be necessary (Fanselow, M. S., & Sterlace, S.R., 2014). Signal detection theory might explanation how natural selection influences our relationship with fear. Signal detection theory describes four possible interactions between threatening stimuli and defensive behavior (depicted in Table 1). When a threat is present, we can either rightly defend ourselves (termed a "hit") or wrongly fail to defend ourselves (termed a "miss). When a threat is absent, we can either defend ourselves unnecessarily (termed a "false alarm") or rightly refuse to defend ourselves (termed a "correct rejection") (Peterson, W., Birdsall, T., & Fox, W., 1954).

When our defensive responses to threats (or lack thereof) are viewed in isolation, it appears that humans should strive to live our lives in a constant state of fear in order to optimize our chances of survival. But fear, and the subsequent changes in behavior, has a cost: fear requires both time and energy that could otherwise be routed towards alternate beneficial behaviors (Fanselow, M. S., & Sterlace, S.R., 2014). A full defensive response interrupts and prevents other adaptive behaviors like eating and sleeping (Estes, W. K., & Skinner, B. F., 1941). However, the evolutionary cost of a fear response, even an inappropriate or unnecessary one, is far less significant than the cost of failing to defend oneself against a legitimate threat. After all, missing a meal or skipping a full night of sleep are temporary problems that don't necessarily affect our ability to survive and

reproduce, but inadequately defending ourselves against a predator, even just once, can result in death. Thus, human evolution favors false alarms over misses, particularly when it comes to threats with higher probabilities of inflicting harm (Ness, R., 2005). One indicator that a threat is more likely than not to cause harm is proximity; proximal threats are more likely to result in damage than distal threats, and thus proximal threats induce more intense expressions of defensive behavior than distal threats (Blanchard, R.J., Blanchard, D.C., 1989). This response is particularly prominent when the threat in question is another human being, as opposed to an object (Rosen, J., Kastrati, G., & Ahs, F., 2017). The ability of humans to trigger defensive responses by invading personal boundaries is a phenomenon that has recently been the focus of a small section of fear conditioning research.

Fear conditioning: A Pavlovian paradigm

Ivan Pavlov is credited with discovering classical conditioning, a paradigm in which a conditioned stimulus (CS) is paired with a biologically relevant unconditioned stimulus (US) that automatically elicits an unconditioned response (UR). Once the association between the CS and US is sufficiently established through repeated pairings, presentation of the CS will automatically elicit CR. In Pavlov's original 1927 experiment, he played a tone (CS) while simultaneously presenting a dog with food (US). Initially, the dog would salivate (UR) only at the sight of food, but eventually the tone became a predictor for the occurrence of food, and thus the dog began salivating (CR) to the sound of the tone, even when food was not yet present (Pavlov, I.P., 1927).

In Pavlov's original experiments, the unconditioned stimulus (the tone) was neutral, meaning it was not biologically relevant enough to intrinsically provoke a

positive or negative reaction from the dog. Fear conditioning, a subtype of classical conditioning, utilizes aversive unconditioned stimuli—painful or threatening stimuli that naturally evoke fearful and defensive responses in the subject organism. Common examples of unconditioned stimuli include electric stimulation, a white noise burst, recordings of human screams, or an air blast applied to the larynx (Lonsdorf, T.B., et al., 2017). These unconditioned stimuli signal potential harm and thus innately evoke defensive responses, which include behavioral, cognitive, and emotional reactions (Vervliet, B., Baeyens, F., Van den Bergh, O., and Hermans, D., 2012) that have been phylogenetically successful in defending the organism against a threat (Fanselow, M. S., & Sterlace, S.R., 2014). Physiological defensive reactions include increases in sweating, heart rate, pupil size, freezing, and blood pressure (Dunsmoor, J.E., Niv, Y., Daw, N., and Phelps, E., 2015).

The first laboratory demonstration of fear conditioning was the infamous Little Albert experiment of 1920. During the experiment, an 11-month-old infant was repeatedly offered a white rat (CS) while the experimenters simultaneously struck a steel bar with a hammer directly behind the infant's head (US). Initially, the infant showed natural curiosity toward the rat, while the clanging noise caused him to topple over and cry (UR). Eventually, the sight of the rat caused the infant to immediately burst into tears (CR), a response which generalized to other white, fluffy objects (specifically, rabbits, dogs, fur coats, and cotton wool) (Watson, J.B., & Rayner, R., 1920). This experiment involved a smorgasbord of unethical practices, but one of the less obvious ones is the lack of an extinction phase, the final phase of any fear conditioning experiment.

Acquisition of conditioned fear. Fear conditioning experiments include two necessary phases: fear acquisition and fear extinction. During fear acquisition, repeated pairings between the CS and US result in a growth in conditioned responding. Hull was the first to develop a mathematical formula for fear acquisition, in which the magnitude of the association between the US and CS determines the magnitude of conditioned responding. Hull viewed fear acquisition as an incremental trial-based process that involves changes in the associative strength between stimuli (the CS and the US), and that view has served as the basis for numerous quantitative models of fear conditioning ever since. The associative strength between the US and CS is largely determined by the choice of stimuli (Hull, C. L., 1943). For instance, utilizing biologically relevant conditioned stimuli, such as snakes or angry human faces, leads to faster fear acquisition and slower fear extinction (Lonsdorf, T.B., et al., 2017). The broad classes of fear conditioning, as defined by choice of stimulus, are cued conditioning and context conditioning, and the two are often combined. In cued conditioning, the CS is a brief signal (an electrical pulse, a white noise burst, etc.). In contextual fear conditioning, the CS is a static feature of the environment (Fanselow, M. S., & Sterlace, S.R., 2014). The Rescorla-Wagner model of fear conditioning explains that contextual conditioning occurs naturally over the course of any cued conditioning paradigm, but context and cued conditioning compete; methodological choices that enhance cued conditioning (such as shorter intervals between the presentation of the CS and presentation of the US) reduce contextual conditioning, and vice versa (Fanselow, M. S., & Sterlace, S.R., 2014, Rescorla, R.A., & Wagner, A.R., 1972).

The amygdala, an almond-shaped collection of nuclei tucked into the temporal lobe, is widely considered to be the centerpiece of the neural circuit that underlies fear acquisition (Kim, J.J., & Jung, M.W., 2006). The basolateral nuclei of the amygdala receive sensory information about fear-relevant stimuli from the hypothalamus, periaqueductal gray, and multiple brainstem nuclei (Adolphs, R., 2013). This is where the association between CS and US is believed to form during fear acquisition (Kim, J.J., & Jung, M.W., 2006). The basolateral nuclei are interconnected with the central nucleus, which projects to downstream areas like the prefrontal cortex, particularly the orbital and medial prefrontal cortex, and these prefrontal cortex areas then regulate the expression of conditioned fear responses (Adolphs, R., 2013) (depicted in Figure 1). In summary, the process of fear acquisition activates the brain's sensory structures, amygdala, and prefrontal cortex.

Extinction of conditioned fear. Fear acquisition is an adaptive process that is critical for human survival in our ever-changing environment (Lonsdorf, T.B., et al., 2017). However, equally critical is the ability to disassociate two stimuli when their relationship has been proven irrelevant. Fear extinction refers to the process of repeatedly presenting the CS without the US in order to disassociate the stimuli, which results in a gradual decay in conditioned responding. Experimental extinction was first described by Pavlov, who observed that extinguished conditioned responses in dogs (the salivation) would spontaneously reoccur after the passage of time (Pavlov, I.P., 1927). Spontaneous recovery, along with other return of fear phenomena such as contextual renewal (the return of the CR in a different context), reinstatement (the return of the CR when tested after a brief reminder of the US), and rapid reacquisition (accelerated re-learning of the

CS-US association), provide strong evidence that the process of fear extinction does not erase or undo the original CS-US association (Dunsmoor, J.E., et al., 2015, Bouton, M.E., Westbrook, R.F., Corcoran, K.A., and Maren, S, 2006). Rather, extinction training forms a new association (CS-No US) that overlays and inhibits the original association (Dunsmoor, J.E., et al., 2015, Vervliet, B., et al., 2012).

Three models shape our modern view of extinction, all of which are based on Hull's view of fear conditioning: the Rescorla-Wagner model, the Pearce-Hall model, and Bouton's model (Dunsmoor, et al., 2015). The Rescorla-Wagner model describes fear conditioning and extinction as error-corrective associative learning that is driven by discrepancies between the expected outcome and the actual outcome. During fear conditioning, the surprise of experiencing the US increases the associative strength between the CS and US (positive prediction error). During fear extinction, the surprising absence of the US decreases associative strength (negative prediction error). However, this model predicts that extinction training causes a simple decrease in the associative value of the CS, and thus doesn't account for return of fear effects (Rescorla, R.A., & Wagner, A.R., 1972). The Pearce-Hall model is based on the same principles as the Rescorla-Wagner model, but adds that extinction is a form of new learning. During extinction training, presentation of the CS triggers both the CS-US association and the CS-No US association, and as the trials progress, the latter association gets stronger while the former gets weaker (Pearce, J.M., & Hall, G., 1980). Bouton expanded on both of these models by pointing out that extinction training renders the CS ambiguous, as its presence can now signal either the US or the lack of the US. Bouton postulates that return of fear phenomena exist because memory retrieval favors the original CS-US association,

because that association was the first one learned and thus its representation in memory is more prominent. The competing associations (CS-US versus CS-No US) elicited during extinction training make fear extinction more fragile than fear learning (Bouton, et al., 2006).

The fragility of fear extinction is reflected in neuroimaging studies of fear conditioning; brain activation during extinction is generally less robust than brain activity during conditioning (Fullana, M.A., 2018). Extinction mostly activates the same amygdala-centered circuit as conditioning, but to a lesser degree, and with more of a focus on the inhibitory circuits of the amygdala: the GABA-ergic intercalated cells, and the inhibitory cells within the basolateral nuclei. Extinction requires the activation of NMDA receptors in the basolateral nucleus, thus confirming that extinction is an active form of new learning, and placing the basolateral nucleus as the site where the CS-No US association is formed (Milad, M.R. & Quirk, G.J., 2012). Outside of the amygdala, there are a number of brain regions implicated in extinction learning: the hippocampus, the cerebellum, the dorsolateral and ventromedial prefrontal cortex, and the dorsal anterior cingulate cortex (Fullana, M.A., 2018). The hippocampus activates during extinction recall, and is particularly sensitive to changes in context (Dunsmoor, J.E., et al., 2015, Maren, S., Phan, K.L., and Liberzon, I., 2013). The cerebellum, specifically the anterior cerebellum (the vermis), is hypothesized to participate in the autonomic aspects of regulating fear responses. The dorsolateral PFC is activated more strongly in extinction than acquisition, possibly due to its role in emotion regulation. Interestingly, the dlPFC is associated with explicit emotion regulation, regulation that requires a deliberate cognitive component, despite the fact that fear extinction has long been considered an implicit form

of emotion regulation (Fullana, M.A., 2018). The vmPFC projects directly to the inhibitory areas of the amygdala, such as the intercalated cells, and also connects to the hippocampus, thus putting the vmPFC in the ideal position to regulate fear. Activation of the vmPFC is necessary for extinction learning, and both the thickness of the vmPFC and the magnitude of its activation correlate positively with the strength of extinction memory (Milad, M.R. & Quirk, G.J., 2012).

Contextual renewal of conditioned fear. Renewal occurs when extinguished conditioned stimuli are encountered outside of the extinction context, and causes a return of the extinguished fear response (Dunsmoor, J.E., et al., 2015, VanElzakker, M.B., Dahlgren, M.K., Davis, F.C., Dubois, S., and Shin, L.M., 2014). Renewal can be caused by a change from the extinction context either back to the acquisition context (ABA style) or to a third, novel context (ABC style), though the latter elicits weaker renewal effects than the former (Vervliet, B., et al., 2012, VanElzakker, M.B., et al., 2014). Extinction and renewal memories experience an inverse relationship with one another; that which strengthens extinction will weaken renewal (Leung, H.T., Reeks, L.M., & Westbrook, R.F., 2012).

The phenomenon of contextual renewal strongly inspired Bouton's theory of extinction, which dictates that activating a second-learned CS-no US association requires input from both the stimulus and the context. Thus, presentation of the CS outside of the extinction context will lack the necessary input required to activate the CS-no US memory, and the original CS-US association will be activated instead (Bouton, et al., 2006).

The hippocampus is hypothesized to regulate context-specific retrieval of extinction memories both directly, through projections to the lateral nucleus of the amygdala, and indirectly, through projections to the vmPFC (Maren, S., et al., 2013). Specifically, imaging studies have demonstrated that successful retrieval of extinction memories (the CS-no US association) activates the vmPFC and the anterior hippocampus (extending into the entorhinal cortex). In contrast, unsuccessful retrieval of the extinction memory causes contextual renewal, a retrieval of the original CS-US association, which activates the striatum, temporal cortex, and posterior hippocampus (Kalisch, R., Korenfield, E., Steohan, K.E., Weiskopf, N., Seymour, B., and Dolan, R.J., 2006).

Social proximity

Fear conditioning and the maintenance of personal space have one key trait in common: both processes are heavily regulated by the amygdala (Ahs, F., Dunsmoor, J., Zielinski, D.E., & LaBar, K.S. 2015). The link between social proximity and the amygdala was discovered in case studies of patient S.M., a middle-aged woman whose amygdala bilaterally degenerated by the time she reached adulthood. S.M. has been informally dubbed "the woman without fear" based on her lack of subjective fear or anxiety and her inability to activate defensive responses in the face of threats (Feinstein, J.S., Adolphs, R., Damasio, A.R., and Tranel, D., 2011). Notably, she also completely lacks a personal bubble. Her preferred distance between herself and an experimenter (0.34 ± 0.02m) was found to be significantly smaller than any control subject (0.76 ± 0.34m, range = 0.44-1.52m, N = 20) across various experimental manipulations (gender of experimenter, gaze direct or averted, subject approached or approaching, starting close or far). She demonstrated a lack of discomfort at close distances, even when the

experimenter was so close that they were touching, and repeatedly stated that any distance felt comfortable. This experiment inspired an fMRI study that showed a higher degree of amygdala response when the experimenter was standing directly next to the scanner, as opposed to when the experimenter stood at a farther distance away from the scanner. The experimenters concluded that the amygdala is differentially activated by proximity to another person, and likely plays a role in determining and maintaining one's personal space (Kennedy, D.P., et al., 2009).

Studies have shown that approaching or violating one's personal space automatically and reliably triggers increased autonomic activity, particularly skin conductance responses, along with defensive behaviors like rigidity, blocking actions, and eye aversion, plus subjective reports of anxiety and discomfort (McBride, G., King, M.G., James, J.W., 1965, Wilcox, L., Allison, R., Elfassy, S., Grelik, C., 2006). Interestingly, this pattern holds true in an immersive 3D virtual reality environment (Wilcox, L., et al., 2006). Human subjects instinctively maintain their personal space in a virtual reality environment, particularly around 3D human avatars, and an approaching avatar consistently triggers avoidant responses in human subjects (Bailenson, J. N., Blascovich, J., Beall, A. C., and Loomis, J. M., 2001). While humans easily distinguish between real life and audiovisual media, it seems that we haven't had enough exposure to the latter for our evolutionary responses to adapt, so we react to human avatars similar to how we react to real humans despite our ability to cognitively delineate the two (Lombard, M., 1995). This pattern of responding makes virtual reality an excellent tool for the exploration of personal space and its relationship with fear conditioning.

This relationship was recently explored for the first time in a multi-experiment virtual reality study coordinated between Duke and New York University (Ahs, F., et al., 2015). In the first experiment, researchers observed an increase in fear-potentiated startle as human avatars appeared at increasingly close distances in front of the subjects, and determined that defensive boundaries are coded in a continuous fashion. In the second experiment, subjects underwent fear conditioning wherein one human avatar was paired with shocks (the CS+) and a different-looking human avatar was not paired with shocks (the CS-). After fear acquisition, the avatars approached subjects in virtual reality and the subjects were instructed to halt the avatars at a distance they would feel comfortable having a conversation (the interpersonal defensive boundary). That comfortable distance was significantly larger for the CS+ as compared to the CS-, implying that personal space is flexibly altered according to the potential threat value of an approaching stimulus. In the third experiment, the subjects underwent a fear conditioning paradigm wherein multiple human avatars were paired with shocks, but those avatars differed in how close they appeared in front of the subjects. The experimenters found that the proximal avatars paired with shocks were more resistant to extinction than distal avatars paired with shocks. Thus, social proximity affects the ease of fear extinction (Ahs, F., et al., 2015).

Present study

The purpose of this study is to examine how social proximity affects the extinction and renewal of conditioned fear. Specifically, this study aims to examine whether participants will experience weaker extinction and stronger renewal to virtual

reality figures that appear to be invading the participants' personal space, as opposed to virtual reality figures that appear a comfortable distance away from the participant.

This study is one of only two studies (along with Ahs, F., et al., 2015) to scrutinize the relationship between social proximity and fear conditioning using an immersive virtual reality environment. This study is also the first study to investigate renewal of conditioned fear, in addition to acquisition and extinction in Ahs' study, and thus attempt to elucidate how context can moderate the effects of proximity on fear extinction and return of fear. Based on Ahs's previous fear conditioning study, and the inverse relationship between extinction and renewal, we predicted that extinction would be impaired and renewal would be heightened for the proximal human avatars compared to the distal human avatars.

Methods

Participants

Fifteen community participants (11 women, 4 men, *M* age = 20.9 years, *SD* = 4.9 years) were recruited using advertisements on Facebook and in the University of Texas Newsletter, and all provided written and informed consent in accordance with the University of Texas Institutional Review Board guidelines. In order to be considered eligible, participants were required to confirm that they could read and speak fluent English, were not prone to nausea or motion sickness, and did not have a history of psychiatric diagnoses. All participants were paid $20 at the completion of their

experimental session. The study was approved by the University of Texas at Austin's Institutional Review Board.

Measures

Skin Conductance Response (SCR): Changes in SCR were measured by placing disposable pre-gelled snap electrodes on the hypothenar eminence of the left palmar surface. In cases in which the electrodes did not adhere to the participant's palm, we attached the electrodes to the middle phalanx of the index and middle finger of the left hand. Changes in SCR were recorded by Acqknowledge software on a computer connected to the BIOPAC MP-150 module.

Stimuli

Unconditioned stimulus (US): The unconditioned stimulus consisted of a 2 millisecond electrical stimulation delivered to the right wrist using disposable pre-gelled snap electrodes. The equipment used to deliver the shocks was a BIOPAC Stimulator Module connected to the BIOPAC MP-150 module. The intensity level of the electrical stimulation was determined by each individual participant prior to the start of the experiment. The instructions for the participant were that the electrical stimulation should be at a level that they deemed to be "highly annoying but not painful." To reach this level, we used an ascending staircase procedure, in which stimulation of increasing intensity was administered until the participant indicated that the level was uncomfortable but not painful. The objective intensity of the electric shock was measured in voltage and

the initial voltage was 15 volts, which was often undetectable by the subject. The maximum shock value on these devices was 100 Volts.

Conditioned stimuli (CS): The stimuli used as CSs were four 3D avatars modeled to appear like adult Caucasian men. The four avatars differed in hair color and style, presence of facial hair, and outfit. All avatars were standing, static, and exhibited neutral facial expressions. Two of the avatars appeared in close proximity and two of the avatars appeared in far proximity. One of the close avatars was paired with electrical stimulation and thus served as the close CS+ and the other close avatar was never paired with electrical stimulation and thus served as the close CS-. One of the far avatars was also paired with electrical stimulation and thus served as the far CS+ and the other far avatar was never paired with electrical stimulation and thus served as the far CS-. As part of the within-subject design, every participant was exposed to all four human avatars. See Figure 2 for images of each stimuli.

Procedure

After signing the provided consent form, participants underwent shock calibration (described above) and SCR electrodes were attached. The Oculus headset was then placed on the participants' heads and adjusted to fit comfortably. All three phases of the experiment (fear acquisition, extinction, and renewal) took place within virtual reality, with breaks in between. Before the first experimental phase, participants were given one minute in the virtual reality environment to look around and explore while the human avatars appeared in front of them, in order to prevent distractions later in the experiment.

Each phase included 40 trials of 12 seconds each: the participant was moved forward for 4 seconds and was stationary for 8 seconds. During the first 4 seconds of each trial, the participants traveled passively through the virtual environment on a straight path with an average velocity of 0.3 m/s. Within the 8 seconds of stationary positioning, the avatar (CS) appears for 6 seconds. The proximal avatars appeared at a distance of 1.5 arbitrary units, and the distal avatars appeared at a distance of 6 arbitrary units. For 60% of the close and far CS+ trials in the fear acquisition phase, the participant would receive electrical stimulation during the last second that the avatar was present.

The appearance of the virtual reality environment differed between phases in an ABA-style design: the fear acquisition phase was presented in Context A, the fear extinction phase was presented in Context B, and the fear renewal phase was presented in Context A (see Figure 3 for images of both contexts). The contexts were differentiated by the textures of the sky, hallway walls, and floor, but both contexts appeared like open-air hallways for the participant to travel down. In each trial, the choice of avatar was pseudo-randomized so that no more than two presentations of each CS-type would occur in a row.

In between each experimental phase were breaks wherein the participants removed the Oculus headset in order to avoid nausea and eyestrain. During the breaks, participants filled out a brief Qualtrics survey asking them to rank the arousal and valence of each human avatar on a scale of 1-9, and then spent one minute watching a relaxing underwater video.

After the renewal phase was completed, the Oculus headset, SCR electrodes, and shock electrodes were removed from the participant. They then filled out a Qualtrics

survey that asked them to estimate the distances that each of the four avatars appeared at, as well as the participants' age, gender, and race. Then the participants were paid $20 and debriefed. See Figure 4 for a diagram of the experiment.

Results

Sample characteristics

This sample included 11 women and 4 men (73% female), a vast majority of which were between the ages of 18 and 28 years old (mean age = 20.933, standard deviation = 4.945). The sample was dominated by Asian and Caucasian participants (40% Asian, 33% Caucausian) (see Table 2).

Skin conductance responses to avatars as a function of conditioning and distance

We predicted that close proximity would weaken extinction and strengthen renewal. Specifically, we predicted that the average SCR for the close CS+ would be higher than the average SCR for the far CS+, and that the average SCR for the close CS- would be higher than the average SCR for the far CS-, in both the extinction and renewal phases. We expected the SCR for the close CS+ would be the highest overall.

SCR was scored if the trough-to-peak response occurred within 0.5s after the stimulus was presented and 0.5s after the stimulus disappeared, and was greater than 0.02 microSiemens. A trial that did not meet these criteria was scored as a zero. All SCR scores were then square-root transformed in order to normalize them.

A two-way repeated measures ANOVA was performed for each experimental phase, with distance (close versus far) and CS type (CS+ versus CS-) as moderators.

Only the renewal phase returned significant results: we found a significant main effect of distance ($F(1,14) = 13.043$, $p = 0.003$) and a significant interaction effect between distance and CS type ($F(1,14) = 8.66$, $p = 0.012$). See Table 3 for details.

In order to explore those results, four one-tailed within-group t-tests were performed for each experimental phase, comparing the close CSs to each other, the far CSs to each other, the CS+s to each other, and the CS-s to each other. Of 12 total t-tests, only 2 returned significant results, both in the renewal phase: SCR was higher for the close CS+ than the close CS- (mean dif = 0.137, $t = 2.855$, $p = 0.006$) and SCR was significantly higher for the close CS+ than the far CS+ (mean dif = 0.156, $t = 3.67$, $p = 0.001$). See Table 4 for details and Figure 5 for a graphical depiction of SCR during the renewal phase.

Changes in subjective valence and arousal of each human avatar

We expected that the participants' ratings of the valence and arousal for each stimulus to fluctuate based on whether or not that stimulus had been paired with a shock in the previous experimental phase, meaning the ratings for both CS-s would change very little across experimental phases, but the ratings for both CS+s would shift after acquisition and again after extinction.

Three one-tailed within-group t-tests were performed for the valence of each stimulus: one comparing the change in ratings from before and after acquisition, one comparing the change in ratings from before and after extinction, and one comparing the ratings from before and after renewal. Of these 12 t-tests for valence, only 2 returned significant results: the valence rating of the close CS+ rose significantly after extinction

(mean dif = 0.867, t = 1.78, p = 0.048), as did the valence rating of the far CS+ (mean dif = 0.933, t = 2.71, p = 0.008). See Table 5 for details.

The same procedure was repeated for the arousal ratings: three one-tailed within-group t-tests were performed for the arousal of each stimulus: one comparing the change in ratings from before and after acquisition, one comparing the change in ratings from before and after extinction, and one comparing the ratings from before and after renewal. Of these 12 t-tests for arousal, 4 returned significant results: the arousal rating of the close CS+ rose significantly after acquisition (mean dif = 1.62, t = 3.267, p = 0.003) and dropped significantly after extinction (mean dif = -1.467, t = 2.71, p = 0.009), and the arousal rating of the far CS+ also rose significantly after acquisition (mean dif = 0.929, t = 2.008, p = 0.033) and dropped significantly after extinction (mean dif = -1.467, t = 2.545, p = 0.012). See Table 6 for details and Figure 6 for graphs.

Participants' estimation of distance for each human avatar

While the mean difference between the estimated distances of both far CSs was 0, a one-tailed within-group t-test revealed that the close CS+ was estimated as significantly closer than the close CS- (mean dif = 1.67, t = 2.017, p = 0.032). See Figure 7 for a graphical depiction of the estimated distances.

Discussion

The present study examined the influence of social proximity on fear extinction and renewal in a virtual reality environment. While no significant differences were found in skin conductance between stimuli during the extinction phase, we did find a main effect of distance and an interaction effect between distance and CS type during the

renewal phase. These results suggest that personal space and context interact in such a way as to influence return of fear phenomena, which holds interesting implications for our understanding and treatment of PTSD.

Implications for PTSD

While enduring a traumatic event, trauma survivors undergo a form of fear conditioning. Cues and contexts present during the trauma become strongly associated with fear, thus forming a CS-US association wherein the conditioned responses resemble strong and often unhealthy defensive responses—such as increased heart rate and hyperventilation that may escalate into a panic attack. If those associations cannot be effectively extinguished later, the appearances of the aforementioned cues and contexts that remind survivors of their trauma can trigger unwanted conditioned fear responses (VanElzakker, M.B., et al., 2014). Notably, extinguishing a conditioned fear is always more difficult when the conditioned stimulus is something biologically salient, such as snakes or ethnic out-group faces, because the association between a CS and a frightening US is stronger (and thus harder to inhibit) when the CS itself is frightening (Dunsmoor, J.E., et al., 2015). Ahs found that an invasion into our personal space is one such biologically relevant stimulus (Ahs, et al., 2015). Since personal space invasions are intrinsically frightening enough to automatically trigger defensive responses, individuals experience difficulty extinguishing fears associated with personal space invasions. Given that failed fear extinction models the development of PTSD, this could partially explain why traumas that involve personal space invasions (such as rape, domestic violence, and kidnapping) predispose their victims to the development of PTSD far more than traumas

that do not involve personal space invasions (such as car accidents and natural disasters) do (Darves-Bornoz, J.M., et al., 2008).

We expected to replicate Ahs's finding that extinction was impaired for CSs that invaded the participants' personal bubbles, and yet we found no differences in skin conductance responses to any of the human avatars during extinction. Given that extinction is always quickened by changes in context, it is possible that the change from Context A to Context B between acquisition and extinction phases was notable enough to overpower the biological salience of personal space invasions and cause participants to extinguish their conditioned fears immediately (Dunsmoor, J.E., et al., 2015, Bouton, M.E., et al., 2006). As in, participants subconsciously understood that the CS-US association was specific to Context A, and did not carry over into Context B. Thus when they encountered the CS+s in Context B without also experiencing any electrical stimulation, they formed a CS-no US association immediately, when usually the formation of that association would have been slowed by its competition with the CS-US association from acquisition (Vervliet, B., et al., 2012). The use of virtual reality might also have exacerbated this effect, as the novelty of virtual reality environments could cause minor changes in context to seem more extreme to participants.

However, we did find significant differences in skin conductance responses to different human avatars during the renewal phase, as hypothesized. Specifically, participants reacted more to both the close CSs than to both the far CSs during renewal, and reacted more to the close CS+ than to the far CS+ during renewal. Taken together, the results from both the extinction and renewal phases of our study suggest that defensive responses to personal space invasions are even more sensitive to context than

previously thought. In terms of PTSD, this means that survivors of assault might only experience PTSD symptoms in response to invasions of personal space if those invasions take place in a context similar to the context of their trauma. For example, survivors of sexual assault might not be bothered by a stranger standing too close to them on the subway, but might experience panic attacks and flashbacks triggered by someone invading their bubble when they're in a bedroom.

The standard treatment for PTSD involves exposure therapy, as modeled by successful fear extinction: exposing patients to cues that they associate with their trauma in a safe environment allows them to mentally create a CS-no US association and eventually eliminated their conditioned fearful responses (VanElzakker, M.B., et al., 2014). Our data from the renewal phase of the experiment suggests that in order for exposure therapy to effectively eliminate overly fearful responses to invasions of personal space for survivors of assault, the therapy must take place in a context similar to that of the original trauma. Otherwise, the patient might undergo perfectly successful extinction of their conditioned fear in the therapist's office, only to find that their newly-formed CS-no US association does not carry over to contexts outside of the therapist's office.

While originally intended only as a way to confirm that the close CSs were truly invading participants' personal space, the participants' estimations for the distance of each human avatar actually provided some intriguing results, with optimistic implications for PTSD treatment. While participants found no difference in the distances of the far CSs, they reported that the close CS+ seemed significantly closer than the close CS-. The fact that the close CS- was perceived as farther away than the close CS+, despite their

identical distances, might suggest that the association of the CS- with safety was strong enough to override the perception of a personal space invasion. This could mean that as long as survivors of assault can learn to associate safety with certain people, such as friends and other loved ones, they can prevent unwanted reminders of their trauma when those people step into their personal space. Taken all together, our results strongly suggest that while invasions into personal space are naturally frightening, that fear can be powerfully suppressed by cues and contexts that are associated with safety.

In addition to recording participants' SCR, an implicit measure of fear conditioning, we also asked participants to rate the valence and arousal of each human avatar before and after each experimental phase, as an explicit measure of fear conditioning. The ratings changed as expected, fluctuating in response to whether or not the human avatar in question was paired with electrical stimulation during the previous experimental phase. This result confirms that valence and arousal ratings function well as an explicit measure during virtual reality studies. Most fear conditioning studies that include an explicit measure utilize shock expectancy, asking participants to answer whether or not they expect a shock as each stimulus appears before them (Lonsdorf, T.B., et al., 2017). However, shock expectancy is a difficult measure to include in a virtual reality study without risking the participants' feelings of immersion in the VR environment. Our study's results indicate that future VR fear conditioning studies would benefit from including valence/arousal ratings as an explicit measure of fear conditioning instead of shock expectancy.

Limitations

The primary limitation of this study was the small sample size (n = 15). However, some of the negative effects of the limited sample size on statistical power were mitigated by the use of a within-subjects design and the use of a well-established fear conditioning paradigm. The sample was also predominantly young women, and thus our results might not generalize to other populations. Future studies should seek a larger sample size with a better spread of age and gender. We also suggest that future studies on renewal and social proximity utilize at least one indoor context, instead of using two outdoor contexts as we did, in order to better generalize results to situations like sexual assault and domestic violence. The use of virtual reality also limited the ecological validity of the study, though less so than the use of 2-dimensional stimuli would have. Future replications of this study could also include other return of fear phenomena besides renewal, such as reinstatement and rapid reacquisition, in order to develop a more comprehensive model of how social proximity can influence PTSD symptoms.

Conclusions

This study was the first to explore how social proximity affects the renewal of conditioned fears. We found that the ability of personal space invasions to trigger conditioned fear responses is deeply influenced by context. Specifically, we found that fear responses triggered by personal space invasions can be overridden by a context or cue associated with safety, but that extinguishing a conditioned fear of personal space invasions might fail to carry over in a return to the original context of fear acquisition. Our results can be used to inform understanding and treatment of PTSD, and can hopefully be used to help patients with PTSD to heal from their trauma.

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Appendix A: Tables

Table 1. Signal detection analysis of fear responses (Fanselow, M.S., & Sterlace, S.R., 2014)

	Danger Present	Danger Absent
Defend	Hit Survival possible	False Alarm Survival guaranteed
Do Not Defend	Miss Survival unlikely	Correct rejection Survival guaranteed

Table 2. Demographic data of participants

Age	N
18 – 20	7
21 – 23	4
24 – 26	2
27 years and over	2
Gender	
Female	11
Male	4
Race	
Asian	6
Caucasian	5
African American/Black	2
Hispanic/Latinx	1
Native American/Alaskan	1

Table 3. Two-way repeated measures ANOVA for each experimental phase.

Fear Acquisition

Source of Variation	SS	df	MS	F	P
Distance	0.0013	14	0.0013	0.0514	0.823922
CS Type	0.057	14	0.057	4.1007	0.062372
Distance x CS Type	0.0001	14	0.0001	0.0092	0.924946

Fear Extinction

Source of Variation	SS	df	MS	F	P
Distance	0.0004	14	0.0004	0.0769	0.785596
CS Type	0	14	0	0	1
Distance x CS Type	0.0014	14	0.0014	0.0725	0.791659

Fear Renewal

Source of Variation	SS	df	MS	F	P
Distance	0.0913	14	0.0913	13.0429	0.002833
CS Type	0.0527	14	0.0527	4.1825	0.060116
Distance x CS Type	0.0909	14	0.0909	8.6571	0.010708

Table 4. One-tailed within-groups t-tests for each experimental phase, comparing pairs of stimuli.

Fear Acquisition

	Close CSs	Far CSs	CS+s	CS-s
Mean	0.064	0.059	-0.007	-0.011
St. Dev.	0.158	0.157	0.195	0.186
t	1.563	1.467	-0.147	0.240
P	0.070	0.082	0.443	0.407

Fear Extinction

	Close CSs	Far CSs	CS+s	CS-s
Mean	-0.011	0.009	-0.004	0.015
St. Dev.	0.102	0.221	0.183	0.124
t	-0.404	0.151	-0.088	0.469
P	0.346	0.441	0.466	0.323

Fear Renewal

	Close CSs	Far CSs	CS+s	CS-s
Mean	0.137	-0.019	0.159	0.000
St. Dev.	0.186	0.107	0.164	0.089
t	2.855	0.671	3.671	0.008
P	0.006	0.257	0.001	0.497

Table 5. One-tailed within-groups t-tests comparing the valence ratings for each stimulus across each experimental phase.

Close CS+

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	-0.643	0.867	-0.267
St. Dev.	1.393	1.885	1.869
t	1.727	1.781	0.552
P	0.054	0.048	0.295

Close CS-

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	0	0	-0.333
St. Dev.	2.082	1.851	1.448
t	0	0	0.892
P	0.5	0.5	0.194

Far CS+

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	-0.214	0.933	0.133
St. Dev.	1.81	1.335	0.990
t	0.444	2.709	0.521
P	0.332	0.008	0.305

Far CS-

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	-0.077	0.143	-0.071
St. Dev.	2.06	1.657	1.207
t	0.135	0.322	0.222
P	0.447	0.376	0.414

Table 6. One-tailed within-groups t-tests comparing the arousal ratings for each stimuli across experimental phases.

Close CS+

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	1.615	-1.467	0.467
St. Dev.	1.850	2.099	1.685
t	3.267	2.705	1.073
P	0.003	0.008	0.414

Close CS-

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	0.500	-0.667	-0.067
St. Dev.	1.506	1.496	1.438
t	1.242	1.726	0.179
P	0.118	0.053	0.430

Far CS+

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	0.929	-1.467	0.200
St. Dev.	1.730	2.232	1.146
t	2.008	2.545	0.676
P	0.033	0.012	0.255

Far CS-

	Change Across Acquisition	Change Across Extinction	Change Across Renewal
Mean	0.143	-0.667	0.467
St. Dev.	1.995	1.838	1.408
t	0.268	1.404	1.284
P	0.396	0.091	0.109

Appendix B: Figures

Figure 1. Diagram of neural projections received by and sent from different nuclei in the human amygdala (Adolphs, R. 2013).

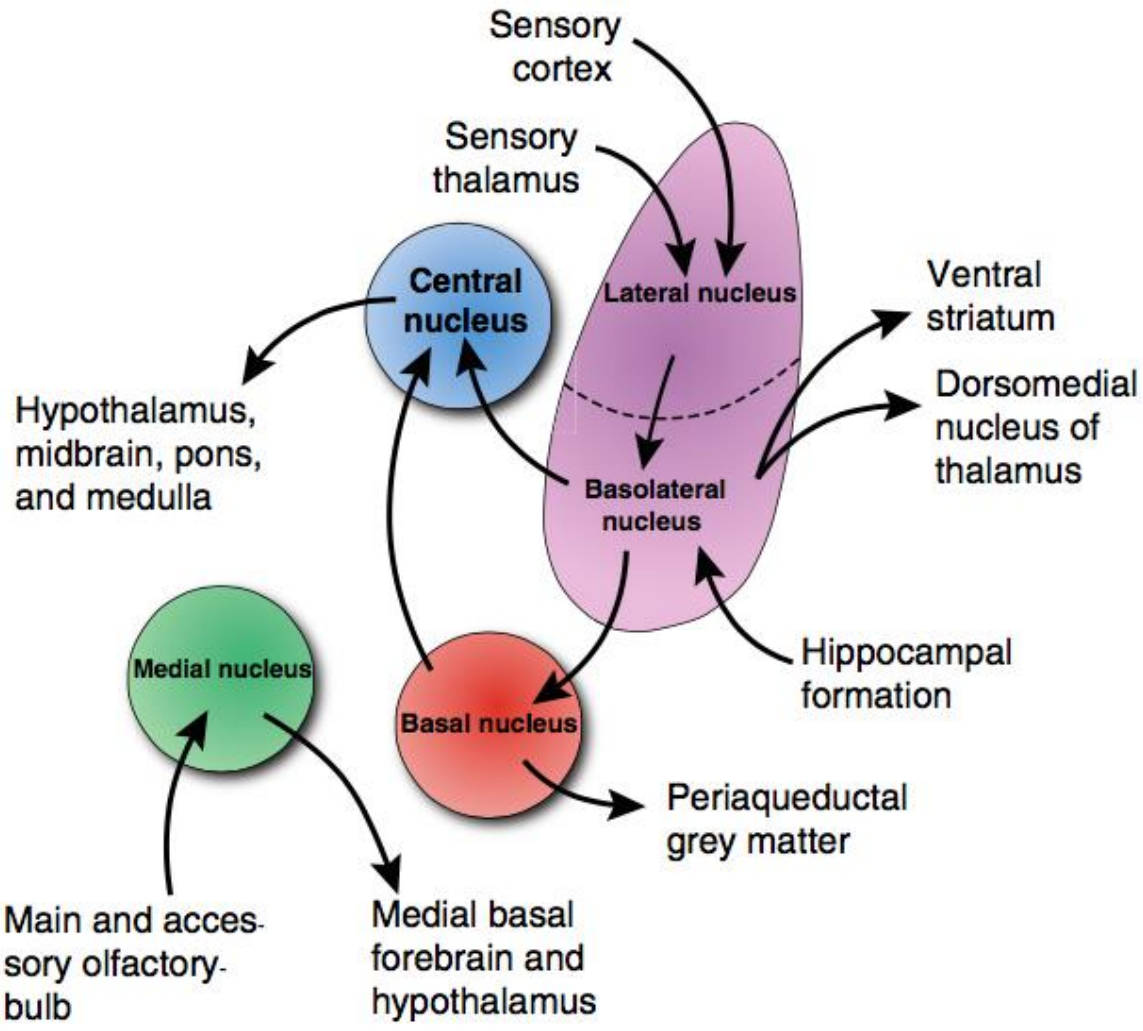


Figure 2. The four virtual reality human avatars used as conditioned stimuli.

	CS+	CS-
Close		
Far		

Figure 3. Context A (above) used during the acquisition and renewal phases, and context B (below) used during the extinction phase.

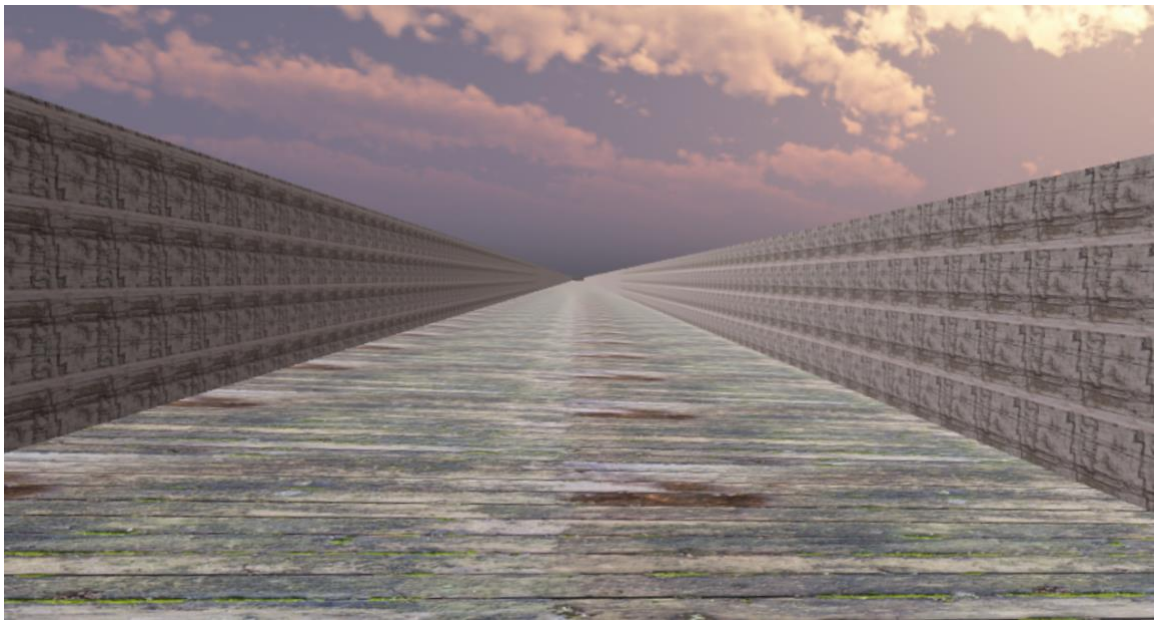


Figure 4. Diagram of the three experimental phases: acquisition, extinction, and renewal.

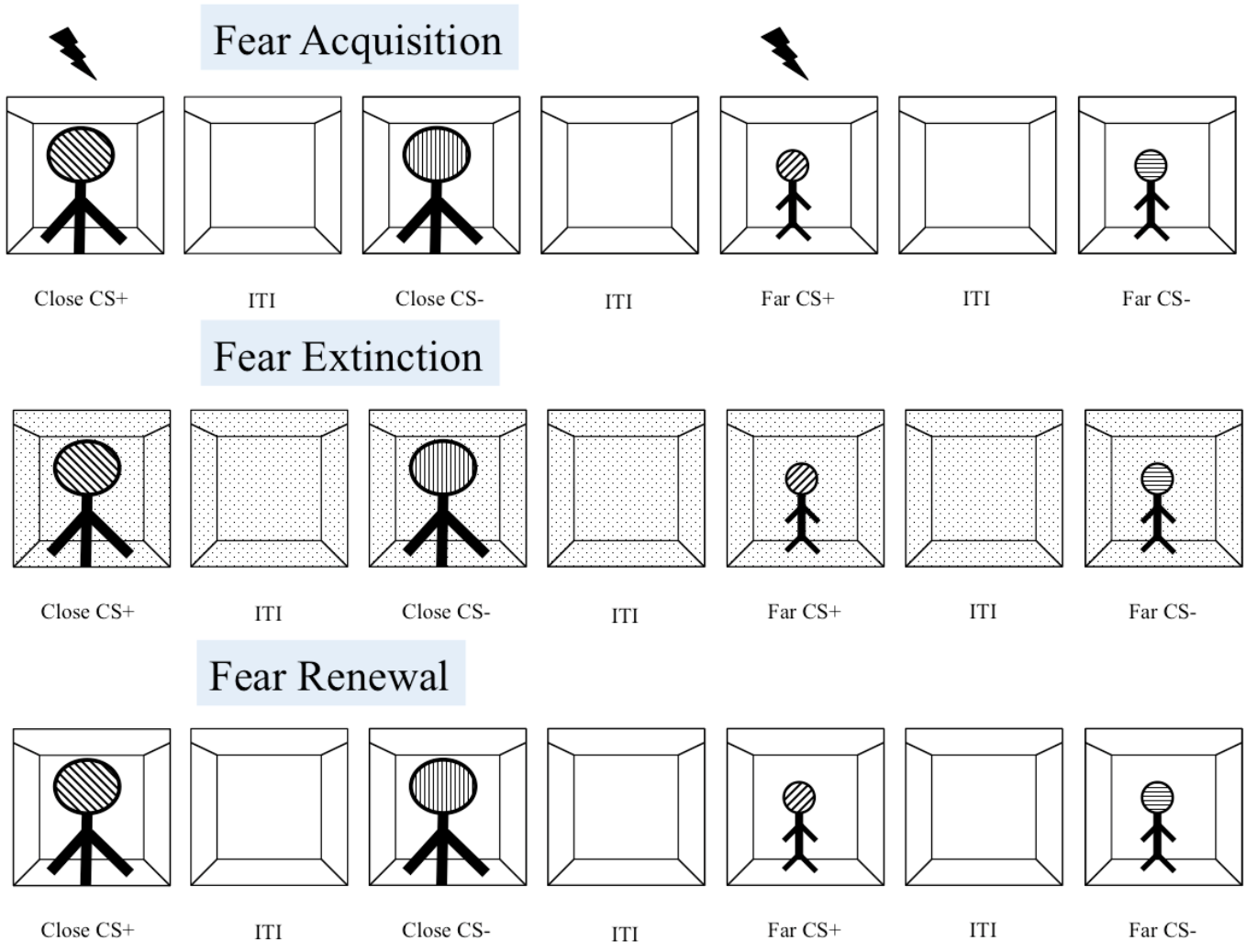


Figure 5. The skin conductance response averaged across participants during the renewal phase.

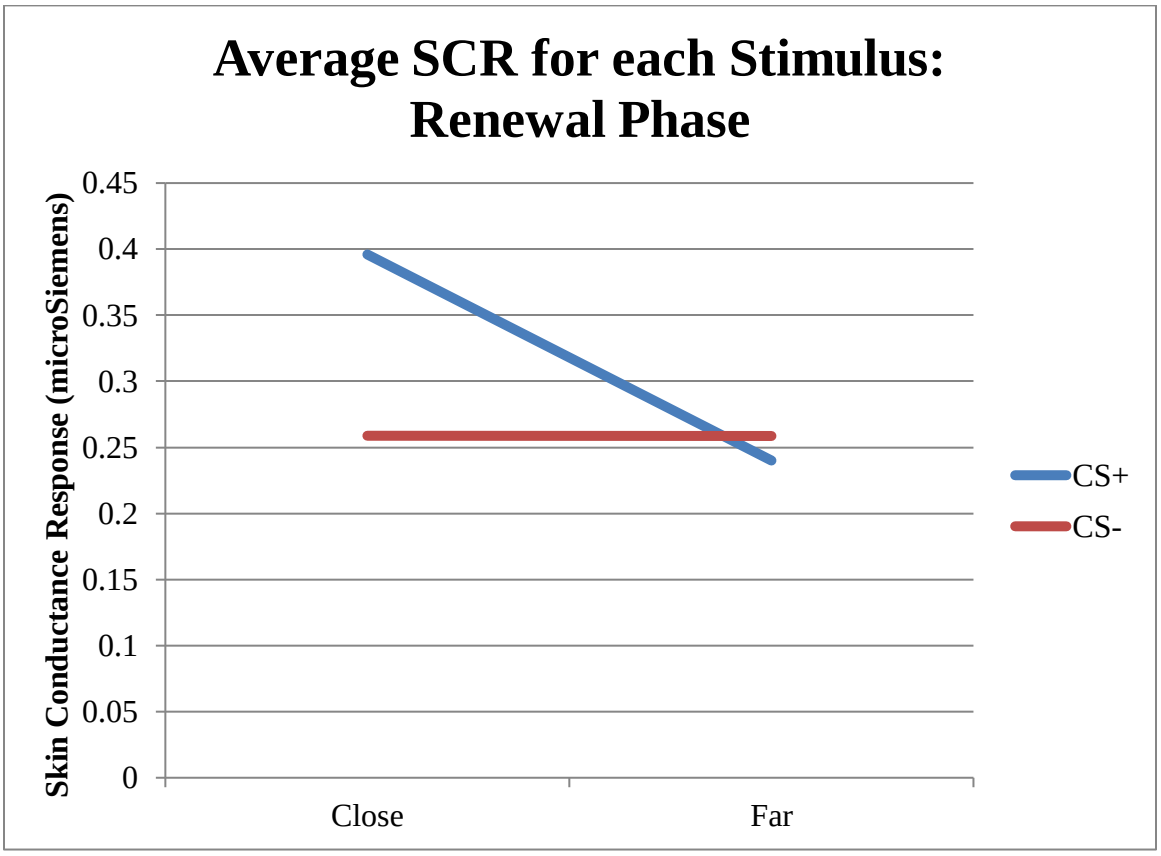
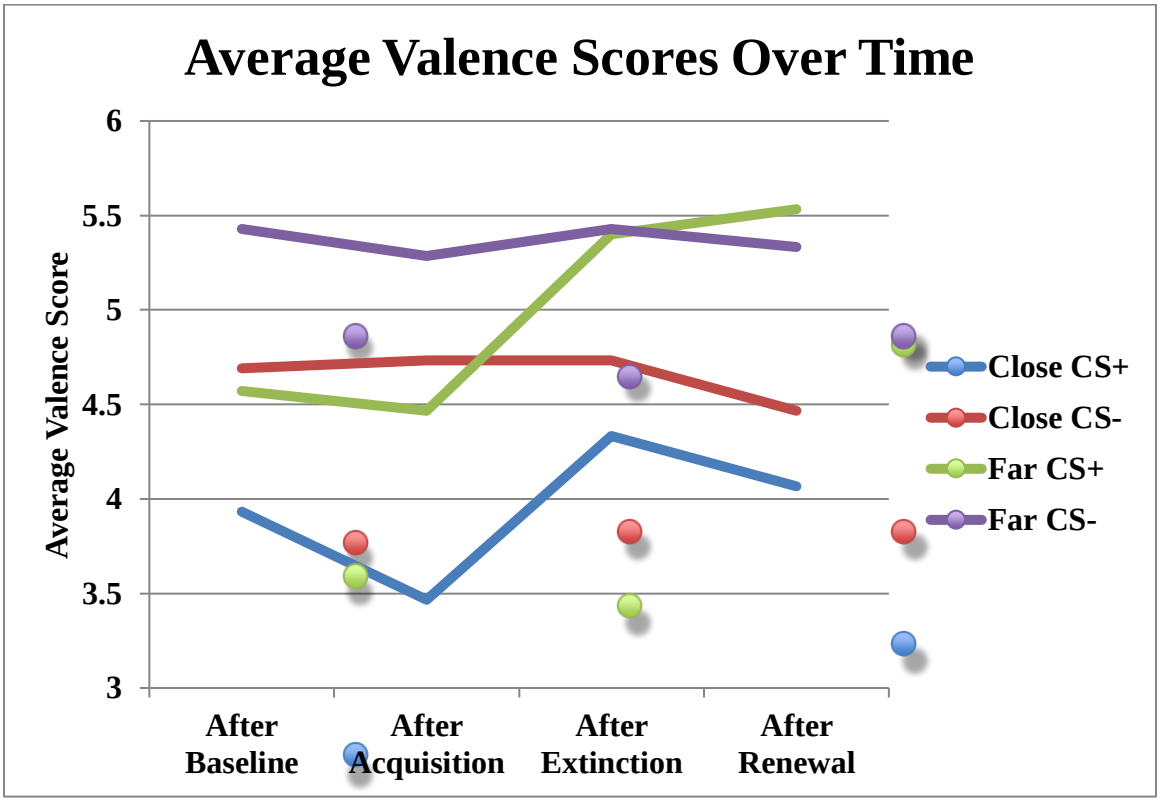


Figure 6. The change in valence and arousal scores over time.



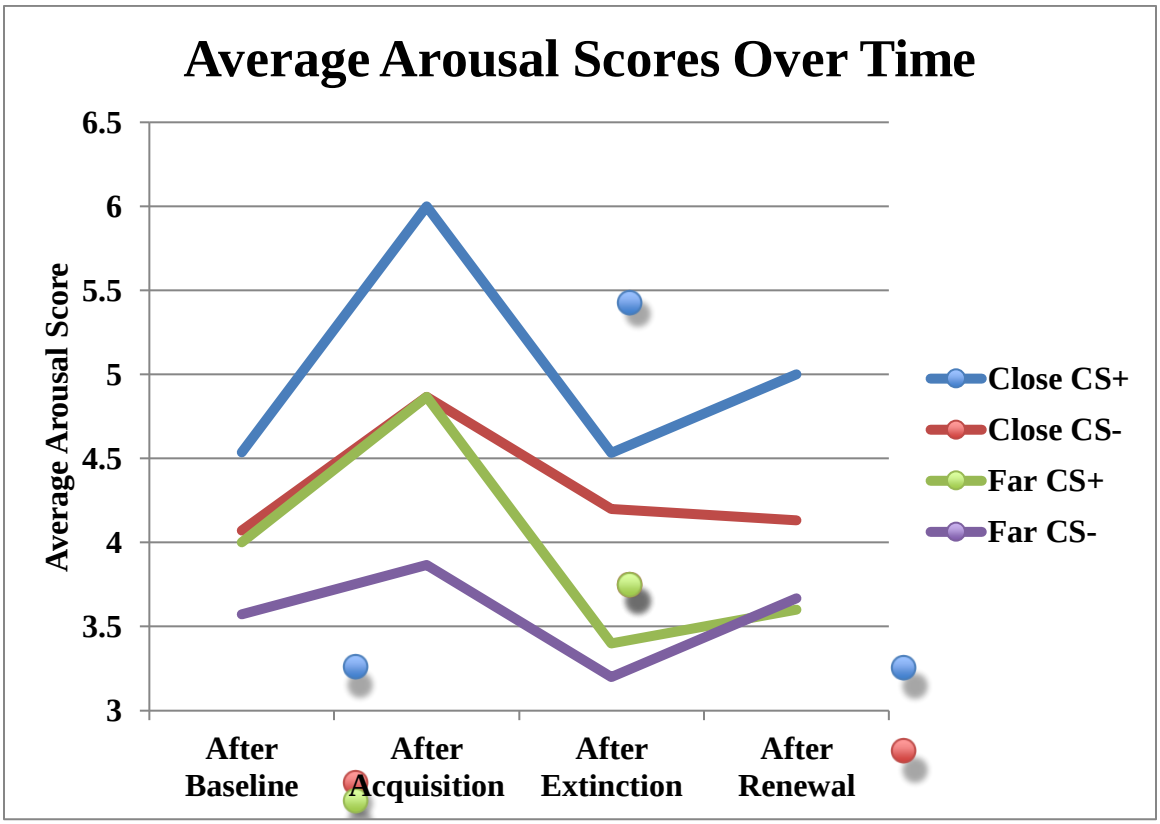
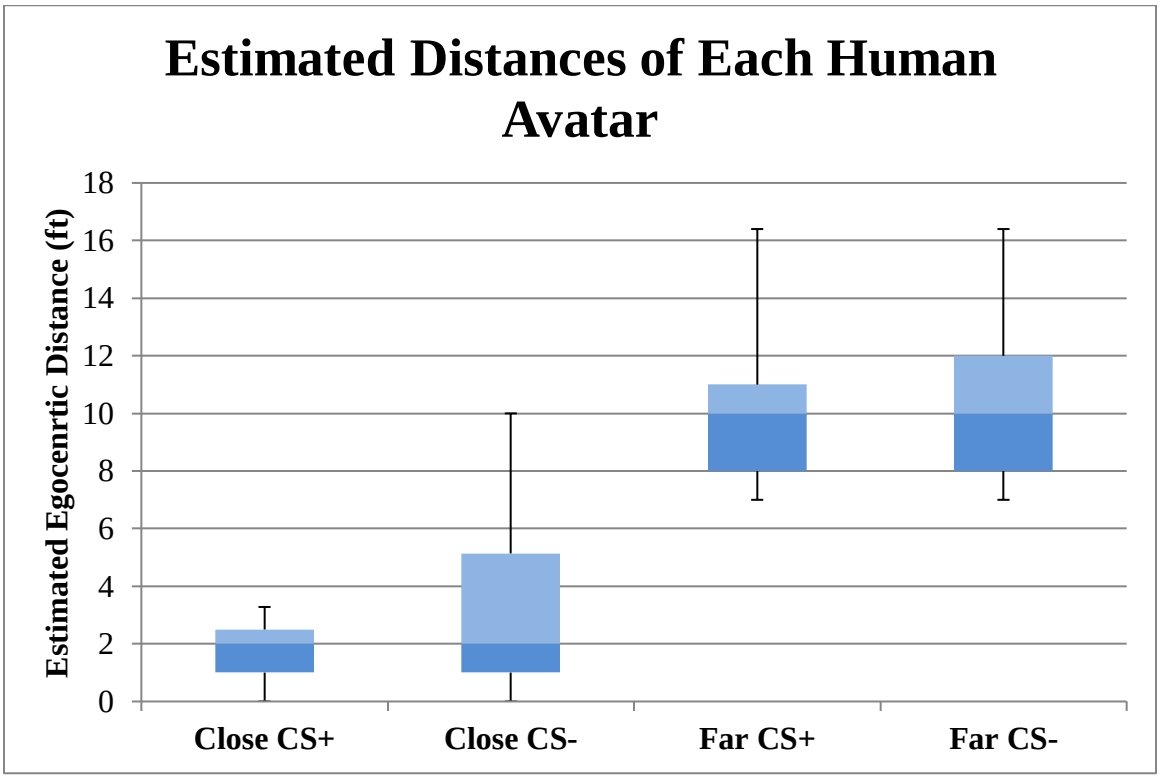


Figure 7. The participants' estimated distances for each stimulus.



Biography

Sophia Toprac was born in Austin, Texas at the stroke of midnight on the spooky evening of October 31st, 1996. Eighteen extremely silly years later, she enrolled at the University of Texas to study Neuroscience, Psychology, and Plan II Honors. She intends to pursue her PhD in Neuroscience, and hopefully someday open her own lab in order to study the neural underpinnings of mental unhealth in the LGBT community. In her free time, she enjoys knitting things badly, watching Vin Diesel movies, and making pretentious comments about literature.